The North Alabama Lightning Mapping Array: Recent Results and Future Prospects

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ABSTRACT: The North Alabama Lightning Mapping Array (LMA) became operational in November 2001 as a principal component of a severe weather test bed to infuse new science and technologies into the short-term forecasting of severe and hazardous weather, principally within the nearby National Weather Service (NWS) forecast offices. A large number of tornadic storms, hailstorms, damaging wind events, non-tornadic supercells, and ordinary non-severe thunderstorms have been observed since the LMA began collecting and archiving this enormous volume of data. The key components of evolving storm morphology we attempt to capture are the time rate-of-change (trending) of storm convective and precipitation characteristics that can be diagnosed in real-time using the NEXRAD WSR88-D Doppler radar (echo growth and decay, precipitation structures and velocity features, outflow boundaries) in conjunction with the LMA (total lightning and its trend, ratio of intracloud to cloud-to-ground lightning- the latter derived from combining the LMA with the National Lightning Detection Network, NLDN). In this paper we provide an overview of LMA observations and products, and discuss the prospects for improving the short-term forecasting of convective weather.

INTRODUCTION

The North Alabama 3-D VHF regional lightning mapping array (LMA, Rison et al., 1999; Krehbiel et al., 2000; Thomas et al., 2000; Goodman et al., 2002) consists of ten VHF receivers deployed across northern Alabama and a base station located at the National Space Science and Technology Center (NSSTC), which is on the campus of the University of Alabama in Huntsville. The LMA system locates the sources of impulsive VHF radio signals from lightning by accurately measuring the time that the signals arrive at the different receiving stations. Each station records the magnitude and time of the peak lightning radiation signal in successive 100 μs intervals within a local unused television channel (channel 5, 76-82 MHz in our case). Typically many hundreds of sources per flash can be reconstructed, which in turn produces accurate 3-dimensional lightning images (nominally <50 m error within 150 km range). The data are transmitted back to a base station using 2.4 GHz wireless Ethernet data links and directional parabolic grid antennas. There are four repeaters in the network topology and the links have an *effective* data throughput rate ranging from 600 kbits s^{-1} to 1.5 Mbits s^{-1}. In real-time operation a flash detection efficiency of ~100% is desired so the data at each station are further decimated (identifying the peak pulse in a 500 μs window, 2000 samples s^{-1}), although the full resolution data are still archived on site and brought back via the links (and by the scientific staff) during periods of inactive weather. The decimation allows tens of sources from each flash to be reconstructed, which is sufficient for the total flash rate of each storm to be computed reliably.

METHODOLOGY

A storm cell identification and tracking algorithm updates the storm characteristics and position with each volume scan, and a nearest neighbor spatial-temporal clustering algorithm associates the cloud-to-ground (NLDN, Cummins et al., 1998) and total (LMA) lightning with each cell to permit trending of radar-derived storm characteristics and lightning rate. The MIT-Lincoln Lab Machine Intelligent Gust Front Algorithm (MIGFA) and visible satellite imagery are used to identify boundaries that may indicate the potential for cloud growth or thunderstorm intensification. The time rate-of-change of storm characteristics and life-cycle trending are accomplished in real-time through the second generation Lightning Imaging Sensor Data Applications Display (LISDAD II) system, initially developed in 1997 through a collaboration among NASA/MSFC, MIT/Lincoln Lab and the Melbourne, FL WFO (Boldi et al., 1998). LISDAD II is now a distributed decision support system with a JAVA-based display application that allows anyone, anywhere to track individual storm histories within the Tennessee Valley region of the southeastern U.S.

A 3D gridded data set is also generated from the full volume LMA VHF data at either 1 or 2 km resolution within a 400 km x 400 km horizontal x 17 km vertical level domain to produce a selectable 1-5 min interval flash density. The NWS Local Data Acquisition and Dissemination (LDAD) system ingests the near real-time flash density grids, which are then provided to the Advanced Weather Information Processing System (AWIPS) forecaster workstation that is used to integrate varied weather data and issue forecasts and warnings. Forecasters can interrogate the data on all 17 horizontal levels as well as the cumulative flash density from all levels. Forecasters can also readily dither between NEXRAD and LMA maps to enhance situational awareness during severe weather episodes. The products auto-update on the forecasters' workstation, with about a 30-sec latency

from the time of ingest. In this way, the forecaster can optimally evaluate the added value of total lightning data within the forecast and warning decision-making process. The LMA domain fully encompasses the warning area of the Huntsville WFO with partial coverage of six surrounding forecast offices.

Key objectives are:

- Characterize thunderstorm initiation and boundary interactions.
- Identify intensifying and weakening storms through the time rate-of-change of total flash rate.
- Evaluate potential of total flash rate trend to improve severe storm probability of detection (POD) and lead time (Williams et al., 1999).

RESULTS AND DISCUSSION

Since the inception of LMA operations in 2001 there has been an abundance of severe weather within the effective domain of coverage extending about 250 km in range from Huntsville, Alabama. For example, during 23-24 November 2001, a major tornado outbreak was monitored by LMA in its first data acquisition effort (30 tornadoes in North Alabama). The single greatest tornado outbreak event of 2002 occurred on 10-11 November, 2002 extending from the southeast U.S. into Ohio and Pennsylvania, with 30 confirmed tornadoes in the 4-state area of Alabama, Mississippi, Tennessee, and Georgia. On 19 March 2003 ten tornadoes were reported in northern Alabama and southern Tennessee. The LMA captured the life-cycles of many of these storms.

Observations at ~0100 UTC on 11 November 2002 (Figure 2) provide an illustration of LMA utility. The NOWRAD[R] NEXRAD radar reflectivity composite and cell IDs indicate the location of storms that produced tornadoes prior to or subsequent to 0100 UTC (Fig. 2a, upper left). The initiation time of the tornadoes and Fujita damage F-scale are summarized in Table 1. Cell B produces a F1 tornado 8 min after this image, Cell D (F2) 53 min <u>prior</u>, Cell E (F0) 9 min and 45 min later, cell I (F3) 8 min <u>prior</u>, Cell J (F3) 8 min later, Cell K (F1) 36 min later, and Cell L (F1) 20 min later. Some of these supercells produced multiple tornadoes; most existing for less than 15 min, although long-lived (50 min life-time) tornadoes were produced by Cells I and L.

Table 1. Tornado chronology for 10-11 November 2002 for the storm cells depicted in Fig. 1.

Cell ID	B	D	E	G	I	J	K	L
*Initiation (UTC) and F#	2335/F?	2335/F2	0109/F?	0225/F1	0052/F3	0108/F3	0136/F1	0120/F1
	0108/F1	0007/F2	0145/F0	0246/F?		0215/F3		0310/F1
	0140/F3			0320/F?				0338/F1
	0200/F2			0405/F?				0422/F1

* Some supercells produced multiple-tornadoes

The 3D LMA source density map (2 km x 2 km horizontal, 500 m vertical grid), which is integrated over the 5-min interval 0100-0105 UTC, provides a snap-shot synopsis of the convective vigor of the various storms (Fig. 2b, upper right). In this 5-min period there were 257,945 VHF sources mapped, representing both intracloud (IC) and cloud-to-ground (CG) flashes. Of the CG flashes (indicated by the + and – symbols), 660 were of negative polarity and 357 of positive polarity. Only 65 of these +CG have peak currents >10 kA, likely indicating that the majority of +CG are misclassified intracloud flashes (Cummins et al., 1998). The East-West and North-South projection of the sources as a function of altitude point to the most electrically active cells. [The lowest level of sources depicted in the E-W and N-S projections increases with height as a function of distance from the array (Earth curvature effect) because the LMA detects the VHF impulses using line of sight]. Trending these density structures (as well as total flash rates) over time can provide the forecaster with ready awareness of the growing and decaying cells (Goodman et al., 2002); updraft intensification, which could signal a greater likelihood for tornadogenesis (Williams et al., 1999); and high risk areas for CG strikes since discharges may travels tens of kilometers before striking the ground. The LMA error analysis, which is currently underway (Koshak et al., 2003), will help determine the usable range of the LMA data (for example, at what range are the density structures and altitude limitations biased by location accuracy).

The time-height resolved LMA flashes (indicated by the narrow columns of VHF pulses) shows a 90 sec period of activity focused on Cell E at 0026:00, ~45 min prior to the reported time of tornado touchdown (Fig. 2c, lower left). Cell E also had a clearly defined hook echo at this time. The NLDN detected 3 negative and 5 positive polarity CGs during this same interval. The individual flashes can be further isolated and animated in time and space, providing tremendous detail on the evolution of each discharge and its relation to the reflectivity structure of the storm.

Finally, the LMA VHF density (shown here at 1 km x 1 km horizontal, 1 km vertical grid resolution) can be displayed on selectable constant altitude surfaces within AWIPS (Fig. 2d, lower right) to facilitate intercomparisons with the Doppler radar reflectivity and velocity. The optimal temporal integration period of the VHF density (1-min, 2-min, or 5-min) is not yet known, but it is anticipated that an LMA update cycle ~ 1-2 min, which is more frequent than the typical 5-6 min NEXRAD volume scan interval, would provide additional lead time for warning on rapidly developing tornadoes.

SUMMARY AND CONCLUSIONS

This paper presents severe weather observations from the 10-11 November 2002 tornado outbreak and describes potential operational products that can be derived from the North Alabama LMA. The continued collaboration between researchers and operational forecasters will provide new opportunities to further evaluate the utility of total lightning data for improving short-term forecasts/nowcasts of convective weather. The additional capability that allows forecasters to integrate near real-time LMA data within NWS operations using the AWIPS workstation offers the potential to increase situational awareness within the WFO, a key element of the warning decision-making process. Additional case studies and the bulk statistical analysis of the storms occurring in the Tennessee Valley will greatly increase the database on severe storms in the climatic regime of the southeast U.S. Additional calibration and validation of the LMA itself is necessary and continuing, but the network now offers the potential to increase our knowledge on the evolution of severe storms and provide additional signatures that can improve the detection of severe storms and increase tornado lead time.

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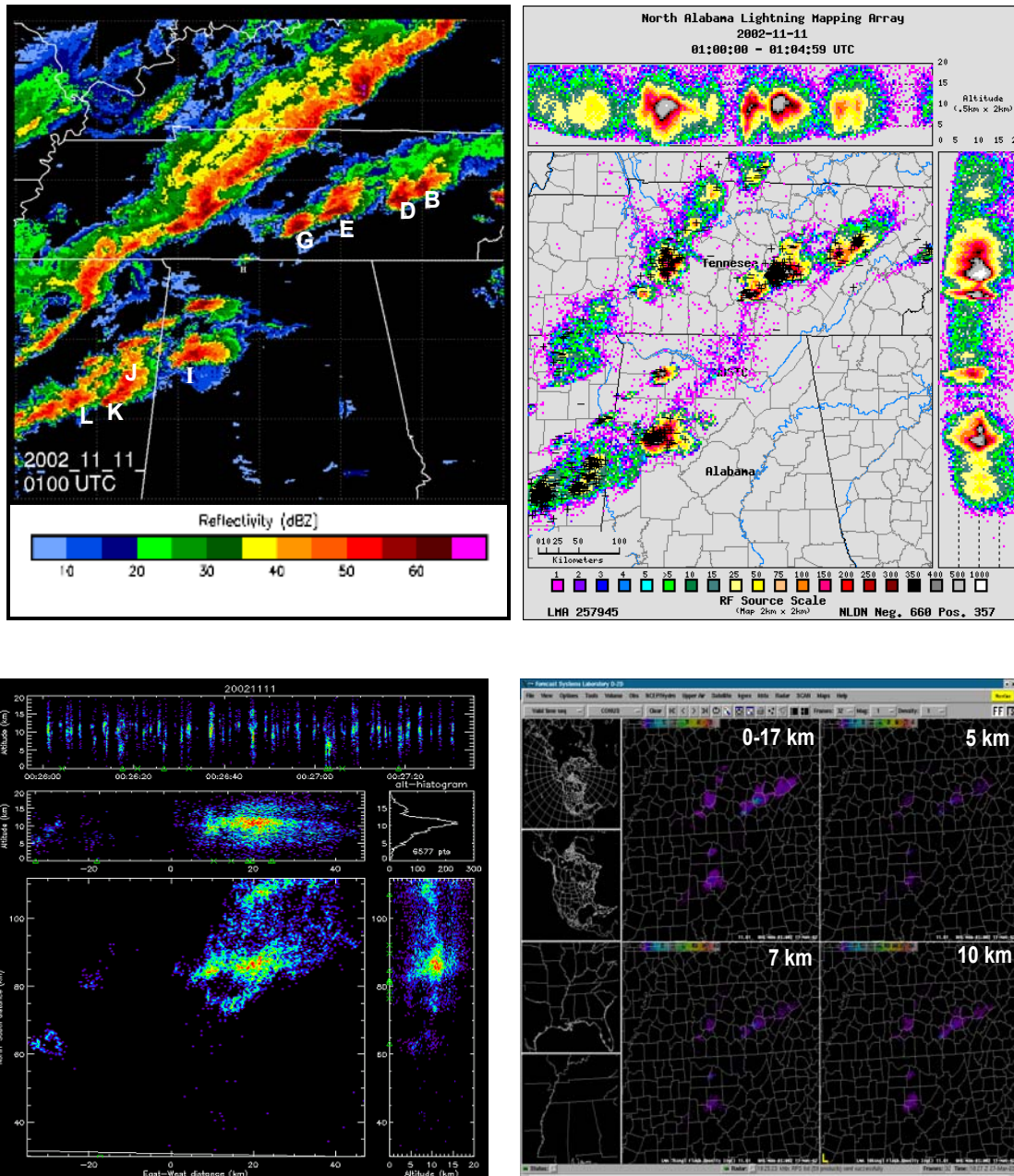
Fig 2. NOWRAD radar reflectivity mosaic at 0100 UTC 11 November 2002 (Fig. 2a, upper left). Tornadic cell IDs as indicated (refer to Table 1). LMA 5-min (0100-0105 UTC) VHF source density with NLDN ground strikes (black, + for positive CG, - for negative CG) overlaid (Fig. 2b, upper right). VHF source density Temporal sequence of LMA VHF sources (cell E) over 90 sec interval (0026:00-0027:30 UTC) with horizontal and vertical projections (Fig. 2c, lower left). Vertical projection above and right of base map shows VHF source density as a function of E-W and N-S distance vs altitude (km). NLDN ground strike polarity shown (triangle for -CG, X for positive CG). AWIPS display of LMA source density (1 km x 1 km, 2-min interval) at 0100 UTC given at four constant height levels as indicated (Fig. 2d, lower right).